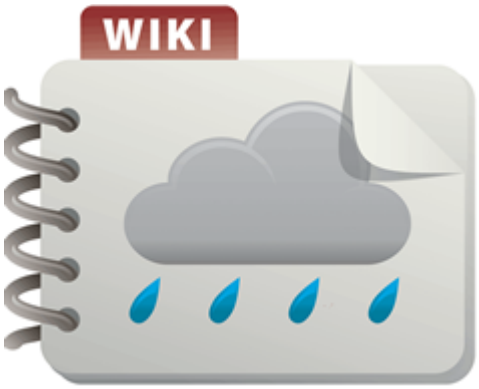


Page Content

Assessing the performance of tree trenches and tree boxes

Green Infrastructure: Trees can be an important tool for retention and detention of stormwater runoff. Trees provide additional benefits, including cleaner air, reduction of heat island effects, carbon sequestration, reduced noise pollution, reduced pavement maintenance needs, and cooler cars in shaded parking lots.

Assessing the performance of tree trenches and tree boxes includes assessing the functionality of the BMP in terms of water and/or pollutant removal and assessing the performance of trees. Both are discussed on this page.

Contents

- 1 Assessing BMP performance
- 2 Assessing tree health
  - 2.1 Methodologies for assessing tree health

Assessing BMP performance

Tree trenches with underdrains are designed to retain solids and associated pollutants by **filtering** (https://stormwater.pca.state.mn.us/index.php?title=Filtration). A typical method for assessing the performance of of BMPs with **underdrains** is therefore measuring and comparing pollutant concentrations at the **influent** and **effluent**. BMPs without underdrains are more difficult to assess, although considering only potential impacts to surface waters, a properly functioning **infiltration** (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_Best_Management_Practices) system is considered to be highly performing.

An online manual (http://stormwaterbook.safl.umn.edu/) for assessing BMP treatment performance was developed in 2010 by Andrew Erickson, Peter Weiss, and John Gulliver from the University of Minnesota and St. Anthony Falls Hydraulic Laboratory. The manual advises on a four-level process to assess the performance of a Best Management Practice.

- Level 1: Visual Inspection (https://stormwaterbook.safl.umn.edu/assessment-programs/visual-inspection). This includes assessments for infiltration practices and for filtration practices (http://stormwaterbook.safl.umn.edu/filtration-practices/visual-inspection-filtration-practices). The website includes links to a downloadable checklist.
- Level 2: Capacity Testing (https://stormwaterbook.safl.umn.edu/assessment-programs/capacity-testing). Level 2 testing can be applied to both infiltration and filtration practices.
- Level 3: Synthetic Runoff Testing (https://stormwaterbook.safl.umn.edu/assessment-programs/synthetic-runoff-testing) for infiltration and filtration practices. Synthetic runoff test results can be used to develop an accurate characterization of pollutant retention or removal, but can be limited by the need for an available water volume and discharge.
- Level 4: Monitoring for infiltration (https://stormwaterbook.safl.umn.edu/assessment-programs/monitoring) or filtration practices

Level 1 activities do not produce numerical performance data that could be used to obtain a stormwater management **credit (stormwater credit)** (https://stormwater.pca.state.mn.us/index.php?title=Overview_of_stormwater_credits). BMP owners and operators who are interested in using data obtained from Levels 2 and 3 should consult with the MPCA or other regulatory agency to determine if the results are appropriate for credit calculations. Level 4, monitoring, is the method most frequently used for assessment of the performance of a BMP.

Use these links to obtain detailed information on the following topics related to BMP performance monitoring:

- Developing an Assessment Program (http://stormwaterbook.safl.umn.edu/developing-assessment-program)
- Water Budget Measurement (https://stormwaterbook.safl.umn.edu/water-budget-measurement)

- Sampling Methods (https://stormwaterbook.safl.umn.edu/sampling-methods)
- Analysis of Water and Soils (https://stormwaterbook.safl.umn.edu/analysis-water-and-soils)
- Data Analysis for Monitoring (https://stormwaterbook.safl.umn.edu/data-analysis)

Additional information on designing a monitoring network and performing field monitoring are found at this link (http://stormwater.pca.state.mn.us/index.php/Calculating_credits_for_tree_trenches_and_tree_boxes#Credits_based_on_field_monitoring).

Assessing tree health

The health of an urban, suburban, rural, or natural forest is rarely limited to individual species. An assessment of forest health should be related to both the individual tree and the collection of trees, including interactions between trees.

Many metrics and methods have been developed for assessment of individual tree health. The concept of "resilience" at the individual and canopy levels is the core of the assessment tools. The majority of these evaluative methods and metrics focus on the response of the individual or evaluative unit to a disturbance regime to quantify the "resilience." The type and capacity of response to the given disturbance and the time it takes to return to the initial qualitative equilibrium state indicate the overall resilience to the disturbance or pressure. Eichorn and Roskams (2013) cite various sources indicating that this return to "equilibrium" is not always return to the initial state, stating that, "open systems will reorganize at critical points of instability." Determining the critical thresholds for certain pressures, disturbances, and changes the system or individual can tolerate before it cannot recover provides a proxy for tree and forest health.

The resilience of the tree individuals and canopy is often difficult to quantify directly for multiple pressures. Rather, indirect measures are often employed for inventory and monitoring of tree health. Measurements and metrics can also be taken both directly (e.g. assessing growth rings from a core) and indirectly (e.g. remote sensing of canopy leaf area). Direct and indirect methodologies are discussed and compared below. It is suggested that the base of monitoring, evaluation, and correlation of forest health be that of overall forest resilience, rather than individual tree health. The foundation of the assessment focuses on the health of the individual as a component of the collection of individuals in the forest canopy. Eichhorn and Roskams (2013) suggest using two levels of monitoring and implementation:

- Level 1 – a large-scale systemic network of the trees within the defined forest area or region; and,
- Level 2 – an individual- or stand-based approach using intensive monitoring plots.

These levels are not distinct in their interactions and the information gained at each level can inform the interactions and information at the other level. Interactions at each of these levels may also be correlated with and inform forest health and interactions at the national or global scale. We suggest future strategies and policy efforts to standardize, create, and implement a larger national, and possibly global, forest assessment tool for monitoring, assessing, and evaluating the health of our forest. Per the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (http://www.unece.org/env/lrtap/workinggroups/wge/forests.html), implementation within the MPCA tree monitoring focuses on the following objectives of Minnesota tree condition monitoring, as a subset of the national and global forest system (Eichorn and Roskams (2013):

- to contribute to a Minnesota-wide early warning system and to a better understanding of tree vitality, including relationships to stress factors and ecosystem disturbances;
- to provide a periodic information on the spatial and temporal variation of tree condition in relation to stress factors;
- to currently document and evaluate the major environmental challenges in Minnesota such as the impact of climate change on forest ecosystem stability;
- to gain information about the impact of biotic and abiotic stressors on crown and tree condition;

- to provide baseline data on the distribution, occurrence, and harmfulness of biotic agents or co-occurring factors in total or parts of Minnesota;
- to validate models regarding stress or risk for trees; and
- to contribute to decision support for forest policy and forest practice with regard to ecological sustainability of forest management.

The methodologies presented hereafter focus on these objects in order to establish a framework for a comprehensive tree monitoring system that can be added to as new methodologies and assessment tools emerge.

Methodologies for assessing tree health

Assessment of tree and forest health can be measured directly or indirectly at either the Level 1 (overall forest) or Level 2 (individual or stand) scales. Indicators of tree condition found in monitoring efforts may be assessed via qualitative and quantitative methods for assessing morphology and architecture (canopy, trunk, fruit, roots, etc.), forest composition, biotic/abiotic agents, growth rate, and age. Eichhorn and Roskams (2013) give an overview of indicators of tree health that may be focused on within a monitoring program at both Level 1 and Level 2, and the targeted areas for assessment and evaluation. A summary of variables they suggest as indicators of tree condition is presented below.

- Primary production
  - Defoliation - estimate the leaf/needle loss in the assessable tree crown relative to a reference standard; estimates range from 0 to 100 in 5 percent classes
  - Apical shoot architecture - estimate the shoot development in relation to the standard of an adaptable tree crown from 0 to 100 in 5 percent classes
  - Fructification - estimate fruits in whole tree crown from 0 to 100 in 5 percent classes
  - Fruit biomass - calculate biomass (mass per hectare) of fruits in litterfall traps from a stand
  - Diameter growth - measure diameter growth, in centimeters, of a stand
- Ecosystem disturbances
  - Determine occurrence and diagnose symptoms and signs of biotic and abiotic agents of whole trees
  - Record number of trees from a plot absent as a result of removal or mortality and cause(s) of absence
- Ecosystem internal regulation
  - Measure or estimate tree age, in years, from a sample of trees
  - Measure tree-related stand structure from a sample of trees

The proposed MPCA tree and forest monitoring system and protocol presented hereafter focuses mainly on direct measurements of individual trees at a Level 1 scale, as a proxy for Level 2 interactions, using the Eichhorn-Roskams (2013) methodology described above.

Direct measurement methods typically employ tree architecture and morphology as a measure and indicator of tree health. The measurements are broken down by foliation (defoliation) of the upper crown/canopy, apical shoot architecture, and fructification. The following table breaks down the areas of evaluation and assessment within each category of tree area.

Qualitative and quantitative evaluation and assessment of trees, by area of tree.
Link to this table.

Area of tree	Qualitative and quantitative evaluation and assessment

Area of tree	Qualitative and quantitative evaluation and assessment
Foliage	Leaves, related to ability of tree to capture light for metabolic processes (photosynthesis), particularly noting: ▪ overall canopy area ▪ openings in the canopy and areas of the openings ▪ quality of leaves, noting any structure or color change ▪ leaf drop, patchiness, or mortality

Apical shoots and overall tree architecture and morphology	▪ Trunk
	  ▪ quality and location of any damage, disruptions and disturbance
	  ▪ type of response noted to disturbance (e.g. scab, open wound, healing, etc.)
	  ▪ bark quality compared to known standards, noting any quality and quantity differences from normal
	  ▪ presence of insects, insect-related activity, and infection
	▪ Branches
	  ▪ overall divergence from normal branching pattern (e.g. no limbs on one side of tree)
	  ▪ branch mortality or abscission, presence of and location per normal growth patterns
	  ▪ no leaf out and bud-related structures set, presence of and location per normal patterns
	  ▪ presence of insects, insect-related activity, and infection

Fructification	Fruit production, as an indicator of reproductive success and health, infection or stress-related response ▪ quality of fruit, noting any damage, infection or pest indications ▪ quantity of fruit. Can be difficult to interpret results, as fruit abundance or deficit can indicate stress (succession-related response of reproductive proliferation and seed band inundation prior to mortality) or success/health (succession-related response of population growth due to abundant resources; excess resources and metabolic byproducts applied seed production).
Roots	▪ Difficult to assess without disturbing tree, with exception of aerial root structures (not found in MN species) ▪ Note any presence and location of roots and root structures above soil finished grade

Recommended monitoring protocol

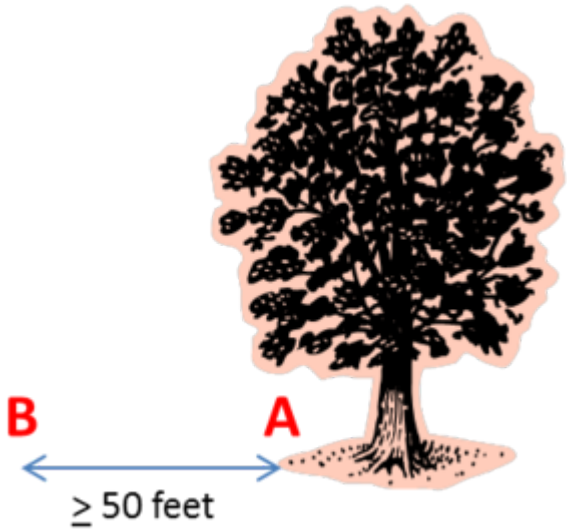
This section provides a recommended monitoring (assessment) protocol. The goal of monitoring is to identify issues or concerns that require a response. Responses to monitoring findings are presented in the Operation and maintenance of tree trenches and tree boxes section of this Manual. Specific troubleshooting responses are presented in a table. This series of responses is mainly on a Level 1, or individual basis, with limited Level 2 assessment suggested via remote sensing technologies. The collection, interpretation, and response to the larger forest (Level 2) health requires collection and collaboration of results between individuals. Large-scale comparative and predictive metrics and an ecosystem-scale assessment system is suggested for future investigation to provide a standardized system for collection and comparison of Level 1 monitoring information.

Frequency of monitoring

Annual tree monitoring is suggested for the crown and apical shoots (all above-ground structures). It is suggested that this could be performed with rapid assessment tools by citizens' monitoring programs, watersheds, municipalities, or other groups. Standardization of the monitoring information collected, date of collection, procedure for collection, and reporting of monitoring for comparison of results between individuals and over larger areas is suggested. Roman et al. (http://www.fs.fed.us/nrs/pubs/jrnl/2013/nrs_2013_roman_001.pdf) (2013) provide a discussion of common practices and challenges for local urban tree monitoring programs.

Positions of collecting monitoring information

Two points should be established and noted on a map or, preferably, a GPS (Global Positioning System) device for consistent results collection. One point (Point A) should be directly underneath the tree for assessment of leaf area coverage and canopy diameter. The second point (Point B) provides quantitative and qualitative results of tree height and vertical leaf coverage, and is suggested to be at least 50 feet from trunk to provide a fixed location for consistent evaluation as the tree grows. A GIS (Geographic Information System) coverage and GPS-based system would aid in consistent evaluation and database assembly for large-scale evaluation and monitoring assessment and responses. Leaf and other tree debris can also be evaluated at any location underneath and surrounding the tree for gathering additional information regarding tree illness, injury, or stress responses.



Schematic illustrating points at which to conduct monitoring/assessment of trees. Each point is fixed and the locations should be recorded using GPS.

Collected information

Information gathered should be assembled into a standard format. The information gathered focuses on the above-ground portion of the tree and surface root presence on an individual/single-tree basis as the standard unit of measurement.

Please note: fructification can give ambiguous indications of overall health, and it should not be used as an independent indication of tree health. Fructification can be used in conjunction with the above-ground structural assessment as a component of the Level 1 (individual or stand) monitoring, but will be more effective as a Level 2 (larger-scale forest assessment) to indicate ecosystem-wide response to stressors, such as insect invasion and long-term drought or reduced soil moisture availability.

Monitoring program

Level 1 monitoring

Level 1 Tree Monitoring focuses on the individual or small unit of individual trees for a field-based assessment tool. This program allows for increased ability to be performed by a layperson or expert, but does not utilize less-accessible programs and methods such as GIS-based or model-based systems that would be more useful at a Level 2 analysis. Other methodologies – electrical conductivity within sap, chlorophyll fluorescence, glucose presence - for Level 1 monitoring were encountered in the literature review, but the tools and/or knowledge required to

perform the analyses or monitoring or the detailed level of information gather were prohibitive for generalized use in this level of monitoring program (Martinez-Trinidad, et al. 2010). It is suggested that this monitoring methodology be standardized in a rapid assessment form for data collection and comparison throughout Minnesota to better perform the Level 2 analyses and provide a greater degree of statistical confidence in results due to standardized methodology.

Assessing the Tree Canopy and Above-Ground Structures

This assessment includes the leaves and leaf structures and/or needles in the tree. Take a photo from Location A and B that captures the extent of the foliage. Take multiple images if necessary, indicating the general direction of view. Complete the following assessment of the canopy, providing additional information of photo-documentation where appropriate.

Assessing the tree canopy and above-ground structures. Take a photo from Location A and B that captures the extent of the foliage. Take multiple images if necessary, indicating the general direction of view. Complete the following assessment of the canopy, providing additional information of photo-documentation where appropriate.
Link to this table.

Defoliation: a relative amount of needles or leaves are missing from the canopy as compared to a reference tree.

Is there any level of defoliation noted?	____ Yes ____ No
If defoliation is present, estimate the percent defoliation	
Describe the location, relative area (ft^2) of the defoliation, percent canopy/leaf loss (% of whole area), and any other notable information regarding each defoliation area noted from visual assessment at Locations A and B. Take photographs as necessary, noting the general direction of view.	

Apical Shoot Architecture: the architecture of the most recent growth of branches in the canopy where the majority of leaves are located and arranged. Answer all of the following questions when examining the apical shoot architecture from Locations A and B and then rate the tree using the Apical shoot scoring system for the Apical Shoot Architecture.

What is the estimated length of a typical apical shoot (inches)?	
Are the upper-most apical shoots alive, as indicated by color and twig turgor pressure (e.g. not dried and brittle in appearance)?	____ Yes ____ No
What is the color of the typical apical shoot?	___ Light brown ___ Dark brown ___ Green ___ Yellow ___ Red ___ Other (specify)

Defoliation: a relative amount of needles or leaves are missing from the canopy as compared to a reference tree.

Is there any presence of the following in the apical branch growth? Mark all that apply, and indicate general location of the noted issues.

___ spear-shaped twigs
___ short twigs
___ lack of bud structures (dormant season only for deciduous trees)
___ a large numbers of twigs emerging from the tips of the next lower level of branching
___ a lack of branch growth in one area or on one side of the tree

Describe any of the noted issues.

Fructification: the fruits and fruiting bodies of trees can indicate much about the health or lack thereof of the individual. Answer all of the following, per the Fructification scoring system.

Is fruit present on the tree? Only note the presence of new fruit from this year, and not "old" fruit from the previous year, as would be distinguished as wrinkled or shriveled in appearance.

___Yes
___ No

Describe the location, relative area covered, and any other notable information regarding the fruiting from Locations A and B. Please take photographs as necessary, noting the general direction of view.

Roots: the majority of the root system should be below ground and relatively difficult to assess and monitor, however, the presence and effects of circling/girdling roots may provide symptoms in tree morphology. Answer all of the following.

Is there a lack of branching or a flat side observed on the tree, or are there any girdling roots observed around the main trunk at or above the soil surface? Note the presence of these features that would indicate root-related issues.

___ Yes
___ No

Describe the location and any other notable information regarding the presence of roots above ground from Locations A and B. Take photographs as necessary, noting the general direction of view.

Assessing biotic and abiotic damages

These pressures are witnessed by signs (direct evidence of a damaging factor) and symptoms (indirect results or evidence of the damaging factor (e.g. leaf proliferation following a windstorm)) of tree health due to biotic and abiotic (environmental) influences. Assess the following damages due to biotic and abiotic factors using the following questions and the Signs and symptoms scoring table and the Symptoms and specification table.

- Leaves/needles show signs or symptoms of damage due to biotic or abiotic factors. Note the number and location of these areas and describe the nature (e.g. color, size, affected part of the tree) of each affected area.
- Describe any of the observed issues designated in the scoring system.

Crown distance assessment

The distance between individual canopies can provide positive and negative aspects to tree health. Some positive aspects of canopies being in close proximity to their neighbors is collective support from wind and other abiotic factors, whereas some negative aspects are increased disease transmissivity, shading, and competition for finite moisture and other resources.

- Rate the overall crown distance between adjacent trees in each perpendicular direction and the monitored individual using the Crown distance scoring system system.
- Describe any of the observed issues within or among the canopy relating to the adjacent canopies in the scoring system.

Level 2 monitoring

Larger-scale monitoring is difficult to assess with standard assessment tools. Large-scale monitoring of crown coverage can be performed by remote sensing methods. These methods include utilizing National Land Cover Data (http://www.mrlc.gov/nlcd2011.php) (NCLD) analyses, high resolution land cover gained from satellite and/or aerial sourced-photography that is interpreted by pattern for land cover, and aerial photography (Eichhorn and Roskams 2013; USDA USFS Northern Research Station (Date Unknown)). These digital models are better adapted for these large scale monitoring efforts, using base data acquired in Level 1 Monitoring in conjunction with climatic inputs, aerial imagery, and other remotely-sensed data that might not be otherwise available or useful at a site or individual scale or level of monitoring. An effective monitoring and overall assessment of a Level 2 scale system was performed for Los Angeles using USFS iTree software, examining and assessing not only the forest health for 30+ years, but the additional impacts and ecosystem services related to the urban forest on the health of the resident population (McPherson, et al. 2011). The application of this protocol to potential Level 2 monitoring by the MPCA warrants further investigation and implementation into monitoring protocol, data assembly, interpretation, trend analysis, composition assessment, resilience analysis, and resource allocation and prioritization.

Several free programs exist to assist in collecting and interpreting the results of Level 2 forest analyses, including Growth Simulator SILVA (http://www.wwk.forst.tu-muenchen.de/research/methods/modelling/silva/) (Technische Universitat Munchen, Germany), FVS (http://www.fs.fed.us/fmsc/fvs/whatis/index.shtml) (USFS), TIPSY (http://www.for.gov.bc.ca/hts/growth/tipsy/tipsy_description.html) (BC CANADA Ministry of Forests, Lands, and Natural Resource Operations), and iTree (https://www.itreetools.org/) (USFS). iTree is a free program with a number of sub-programs that has been generated by the US Forest Service (USFS) to assist in the measurement of a number of tree-related inputs such as evapotranspiration, canopy intereception, water use, carbon sequestration, and other factors. iTree Canopy (http://www.itreetools.org/canopy/) is suggested for potential use in this Level 2 analysis due to the relative ease of inputs and availability of data required, as it is based on the Google maps imagery which is updated frequently and reflects current patterns using a relatively high-resolution satellite image source. This program may provide a standardized base of comparison and interpretation of results of Level 1 assessments to provide assessment and guidance for Level 2 monitoring, pattern and trend analysis, and large-scale responses by scientists, policy-makers, government officials, and citizens alike.

Scoring tables

- Apical shoot scoring system
- Fructification scoring system
- Signs and symptoms scoring table
- Signs and symptoms scoring table
- Crown distance scoring system

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Related pages

- Overview for trees
- Types of tree BMPs
- Plant lists for trees
- Street sweeping for trees
- References for trees
- Supporting material for trees

The following pages address incorporation of trees into stormwater management under paved surfaces

- Design guidelines for tree quality and planting - tree trenches and tree boxes
- Design guidelines for soil characteristics - tree trenches and tree boxes
- Construction guidelines for tree trenches and tree boxes
- Protection of existing trees on construction sites
- Operation and maintenance of tree trenches and tree boxes
- Assessing the performance of tree trenches and tree boxes
- Calculating credits for tree trenches and tree boxes
- Case studies for tree trenches and tree boxes
- Soil amendments to enhance phosphorus sorption
- Fact sheet for tree trenches and tree boxes
- Requirements, recommendations and information for using trees as a BMP in the MIDS calculator
- Requirements, recommendations and information for using trees with an underdrain as a BMP in the MIDS calculator

Links to pages discussing assessment of other BMPs can be found at this page (http://stormwater.pca.state.mn.us/index.php/Category:Assessing_performance).